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SOIL CONDITION AND DISTRIBUTION OF MICRO-ORGANISMS *

In recent years much attention has been given to the distribution of bacteria and other classes of soil micro-organisms in soils of different types and subject to varied cultural operations. Thus, S. C. Vandecaveye and H. Katznelson (1) demonstrate wide variations in the numbers of bacteria, fungi, and actinomyces in soils of different type. Numerous soil bacteriologists, *e.g.*, T. Gibson, (2) H. J. Conn, (3) A. S. Newman and A. G. Norman, (4) have extended this kind of investigation and data obtained indicate that each of the major genetic types of soil tends, normally, to support a microflora characteristic in respect both of total populations and of balance of species. This accords with the fundamental view that factors which are influential in controlling microbiological activity in soils—temperature range, moisture status, aeration (together with the resulting nutrient status)—are also those mainly concerned in soil genesis.

In general the total population of micro-organisms is greater in surface than in sub-soils [Newman and Norman (4)], but in soil-to-soil comparisons moisture content appears to be a dominant factor. Relationships between temperature, moisture, and the microflora of soils are traced by D. Fehér (5). In Palestinian soils examined by M. Winnik (6) the influence of moisture content on bacterial numbers seems to overshadow that of soil type or treatment. According to N. James and M. L. Sutherland (7) the relationship between bacterial population and soil moisture content is a logarithmic one. Under more extreme conditions H. Z. Gaw (8) observes that the protozoal numbers in rice field clay approached 2000 times that of a poor and barren sand. In a comparison of microbial distribution in a moorland and in a forest podsol, G. Ruschmann and L. Pozdena (9) indicate that in the former the number of organisms is smaller than might be anticipated from the relatively high water content and offer the explanation that only a portion of this water content is physiologically available and that the available water supply is probably a limiting factor in biological activity. The much lower numbers in the podsol are traceable to its

* Abstracted from the section on "Soils and Fertilisers" by A. G. Pollard, B.SC., F.R.I.C., Reports of the Progress of Applied Chemistry for 1943, issued by the Society of Chemical Industry, London.

high acidity and lack of mineral nutrients. In the arid soils of the north and central Sahara examined by C. Killian (10) the moisture conditions are generally adverse to bacterial growth and the supply of nutrients becomes the dominant factor in the distribution of bacteria.

The characteristic microflora of soils may be modified temporarily by cultural treatments notably by the addition of organic manures. T. Gibson (2) records that the addition to soil of organic manures, especially dung, causes a marked increase in microbial population presumably by improving water conditions and providing additional nutrients. Aerobic, sporing bacilli appear to multiply markedly under these conditions. These effects tend gradually to disappear. The decomposition and disappearance of the organic matter is associated with a gradual return of bacterial numbers to the original level. The process is repeated on further addition of organic manure. Artificial fertilisers have a much smaller effect [A. G. Lochhead (11)]. In chestnut-coloured soils A. A. Ringer (12) finds a large population of micro-organisms in spite of the small humus content, but in this instance also, application of fertilisers or, especially, of dung leads to notable increases in bacterial numbers.

References

(1) *Soil Sci.*, 1940, 50, 295.
(2) *Comm. 3rd Internat. Cong. Microbiol.* Abs., 1939, 304.
(3) *Ibid.*, 303.
(4) *Proc. Soil Sci. Soc. Amer.* (1941), 1942, 6, 187.
(5) *Comm. 3rd Internat. Cong. Microbiol. Abs.*, 1939, 305.
(6) *Ibid.*, 308.
(7) *Canad. J. Res.*, 1940, 18, C, 435.
(8) *Nature*, 1941, 147, 390.
(9) *Zentr. Bakt.*, 1942, II, 105, 213.
(10) *Ann. Agron.*, 1940, 10, 56.
(11) *Comm. 3rd Internat. Cong. Microbiol. Abs.*, 1939, 303.
(12) *Pedology*, 1940, No. 4, 76.

GRANULATION OF ARTIFICIAL FERTILISERS *

BY

A. G. POLLARD, B.SC., F.R.I.C.

A subject of considerable interest at the present time is that of the production of granulated fertilisers. The increased use of fertiliser drills has drawn attention to the physical properties of fertilisers which decide the ease of their passage through the drill, the property which our American friends refer to as "drillability". Spherical granules of approximately uniform size would appear to be the ideal for this purpose. Fertilisers prepared in this form would also possess other advantages, *e.g.*, elimination of segregation of component materials during transport or in the drill hoppers, minimising of "caking" in storage, and obviating, at least in part, the "conditioning" process in the factory. It is also claimed that fertilisers drilled in granular form are more efficient then those applied in other forms by other types of distributor. The benefit of drilling as compared with broadcasting and harrowing lies primarily in the placing of the bulk of the fertiliser in a position relative to the plant in which its utilisation will be at optimum. The action of fertilisers in the soil is less intense but more persistent when applied in the form of granules, than when in crystalline or more finely divided condition. This is of more particular importance in the case of fertilisers applied at seed sowing or as a top-dressing when the young seedlings have emerged. Germination or seedling injury is stated to be minimised by the employment of fertilisers in the granular or pellet forms.

Against the advantages claimed for the use of granulated fertilisers must be set the cost of the process, which frequently involves moistening and subsequently drying the product after addition of lime, chalk, or a binding material, with accompanying risk of chemical deterioration of the material or, in mixed fertilisers, or reactions occurring between the components. It has been suggested also that if granulation became the standard practice in the manufacture of fertilisers there might follow a severe restricition in the range of mixed fertilisers (in respect of chemical composition and nature of constituents) offered for sale. The detail of the granulation process, as now envisaged would of necessity depend on the nature and proportions of the constituent materials and each modification of composition might demand a corresponding change in the process adopted. Such production difficulties would be minimised by granulating individual fertilisers, which could then be mixed as required. Such a practice however, might well introduce other manufacturing problems and would eliminate some of the benefits for which granulation is advocated.

Another criticism of the general adoption of granulation as a standard practice is that it would place a premium on the less bulky or "concentrated" fertilisers and restrict the inclusion of organic materials in fertiliser mixtures. In many instances the cost of pelleting is stated to be small and, moreover, the incorporation of organic materials facilitates the process. The reduction in the bulk of organic materials by pelleting is considerable, *e.g.*, dry powdered poultry manure weighed 25 lb. per bushel, whereas in the pellet form the bushel weighed 59 lb. Satisfactory pellets of inorganic materials can be made with diameters of 3/32 to ½ inch. Compressed cubes up to 1 inch (ammonium sulphate) are also described.

* Abstracted from section on "Soils and Fertilizers" by A. G. Pollard, B.SC., F.R.I.C., Reports of the Progress of Applied Chemistry issued by the Society of Chemical Industry for 1943.

THE SIGNIFICANCE OF CARBON-NITROGEN RATIO IN SOILS GROWING COTTON

(I) The Cotton Soils of Queensland, Australia

BY

F. HARDY

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(I) Introduction

The writer's interest in the nitrogen relationships of cotton was first aroused by correspondence between Mr. W. G. Wells, Director of Cotton Culture of the Queensland Department of Agriculture and Stock, and Dr. T. G. Mason, Plant Physiologist, Cotton Research Station, Trinidad, which he was permitted to see through the courtesy of Dr. Mason. In June, 1930, Mr. Wells submitted for comment a memorandum describing certain peculiar features of the behaviour of cotton growing under various conditions in Queensland, Australia. Previous to 1920, the crop was mostly grown in South Queensland, but in more recent years, its cultivation has been extended northwards into the tropics. Several different soil-types have been utilised for cotton cultivation and their various reputations and peculiarities with regard to the differential behaviour of the cotton plant when grown successively year after year was the direct cause of the correspondence referred to above.

Most of the soils produce good crops of cotton, during the first 2 or 3 years after being brought into cultivation from scrub, but after 5 or 6 years, particularly if planted late, the cotton plants may begin to show rank growth. They produce large, dark green, sappy leaves especially in rainy weather, and they may reach a height of 6 or 7 feet. Moreover they become susceptible to attack by Corn Ear Worm (*Heliothis*) and to Jassid leaf-hoppers. This behaviour is generally termed "bolting".

The length of time of cropping a given area of land before bolting becomes manifest varies greatly and seems to depend mainly on soil-type. Thus certain loamy phases of the Alluvial Soils, represented at the Callide Cotton Research Station situated in the centre of the Queensland Cotton Belt, produce satisfactory cotton crops for six or more successive years after bringing in from old grass, burnt off and the stubble ploughed under. Subsequently the plants tend to bolt when the rains set in, and much boll-shedding occurs, which, together with insect damage, greatly reduce the final yields. Other soil-types, such as certain clay phases of the Alluvial Soils, and also the Red Earths, although they may support satisfactory crops during the first year or two, soon exhibit the bolting habit, especially if planted late, and the plants become particularly susceptible to Jassid attack.

Cotton plants that tend to bolt exhibit most of the symptoms of nitrogen excess, whereas the more satisfactory plants, typical of new lands and producing good crops that do not bolt, exhibit many of the features of nitrogen deficiency or bare sufficiency, namely, tough small leaves having a yellow-green colour and reddish stems and petioles, as well as low stature (being seldom more than 4 feet tall) and a general "open" structure.

Chemical Soil Data: In order to detect possible differences between soils supporting cotton crops of varying behaviour and performance, chemical analytical data were procured and submitted to us by Mr. Wells as appendix to his typescript memorandum. These data refer to samples of soil representative of three main soil-types which may be designated, (I) Alluvial Soils. (II) Black Earth Soils, and (III) Red Earth Soils, These comprise the main cotton soils of Queensland; they are briefly described below.

Descriptions of the Soil-types

(I) ALLUVIAL SOILS: These vary greatly in colour and texture. Sandy soils occur on the levees giving place to loams, clay-loams and clays over the flats. The better-drained levee soils (*e.g.* Biloela type) usually exhibit clay-pan at 12 to 18 inches depth overlying alkaline subsoil resting on gravelly-sand in which specks or nodules of calcium carbonate mark the downward limit of water percolation, around 48 inches. Other similar soils (*e.g.* Upper Burnett type) show a deeper-seated clay-pan and no lime accumulation, though the subsoil is highly alkaline. These soils might perhaps be classified as *Brown Earths* having marked calomorphic features. Their contents of available phosphate and potash are usually very high.

The poorer-drained, lower-lying soils generally show hydromorphic features due to waterlogging, induced either by impervious structure or by depressed topography. They usually comprise grey or black clays.

The natural vegetation of the Alluvial Soils shows a predominance of *Eucalyptus* species.

(II) BLACK EARTH SOILS: According to Prescott,* Black Earths in Queensland are "associated with basalts or with carboniferous formations" (Soft limestones and calcareous shales). He describes them thus:—

"In profile, these soils are black or very dark grey ..... calcium carbonate streaks and small concretions are common throughout". In some phases, the colour is chocolate, yellow-brown or dark-grey becoming paler with depth. Concretionary lime often occurs at 18 to 30 inches. Potash status is said to be generally high.

The natural vegetation is Brigalow Scrub, named after the chief component, *Acacia harpophylla*.

* "The Soil Zones of Australia"; J. A. Prescott, *Soil Research*, 1933, III, pp.133-145. *See also*, "An Examination of Some Soils from Tropical Australia"; J. A. Prescott and H. R. Skewes, *Trans. Roy. Soc. S. Australia*, 1941, 65, pp.123-139.

(III) Red Earth Soils: The Red Earths or Red Loams of Eastern Australia, according to Prescott,† are mainly derived from basalt and are "highly permeable ..... in spite of a high proportion of fine particles". They are usually "very deep and uniform, the parent basalt in many cases being 15 to 25 metres from the surface". Further, "these Red Loams do not possess any obvious profile". Their colour is blood-red to full depth and they are often very highly acid, except in the surface layer immediately after burning. Both phosphate and potash status are usually low.

The natural vegetation is chiefly rain forest, especially near the coast; in drier districts it is Soft Vine Scrub.

The laboratory data appertaining to these soil samples analysed in Queensland are set out in the accompanying table (Table I), in which they are arranged in order of diminishing carbon-nitrogen ratio.

† "Some Red Basaltic Soils from Eastern Australia"; J. A. Prescott and J. S. Hosking. *Trans. Roy. Soc. S. Australia*, 1936, 60, pp.35-45.

Discussion of Data (Table I): It will be noticed in Table I that, in spite of the fact that both organic matter and nitrogen contents vary widely in these soils, their carbon-nitrogen ratio sharply distinguishes them according to their behaviour when utilised for growing cotton. It also differentiates the three main soil-types from each other. In general, the highest values for C/N characterise newly-cultivated Alluvial Soils producing satisfactory crops of cotton, whereas the lowest values are given by Red Earth Soils that have been under cultivation for some time and which produce only fair to poor cotton crops liable to severe attack by insect pests. Values for Black Earth soils are intermediate; cotton crops supported by these soils are fair to good; they are sometimes attacked by insects, especially when planted late in the year. The critical C/N ratio differentiating satisfactory from unsatisfactory soils appears to be about 7.0, but the depth of soil sampling is not definitely stated, so that the general application of this rule to other cases is at present precluded.

Table I

Laboratory Data for Typical Queensland Cotton Soils

Samples analysed in Queensland at instigation of W. G. Wells, 1930

(Depth of sampling not stated; probably 7 ins.)

Soil No.	Cropping and crop reputation	Total O.M. %	Total N %	C/N Ratio	Avail. P_2O_5* p.p.m.	Avail. K_2O† p.p.m.	N/K_2O
(I) Alluvial Soils							
1	Cotton 3 yrs. Good crops each year	1.74	.051	*19.8*	59	282	1.7
2	Cotton 1 yr. Very good crop	2.63	.144	*10.5*	113	398	3.6
3	Ditto. ditto.	3.09	.176	*10.2*	117	464	3.8
4	Cotton 4 yrs.	3.45	.217	*9.2*	75	416	5.2
5	Cotton 3 yrs. Good crops each year	1.21	.076	*9.2*	100	342	2.2
6	Cotton 4 yrs.	3.68	.268	*8.6*	112	638	3.3
7	Cotton 3 yrs. Good crops each year	3.27	.225	*8.4*	175	480	4.7
8	Ditto. ditto.	1.50	.113	*7.7*	59	146	7.8
9	Ditto. ditto.	2.15	.170	*7.3*	73	196	8.7
(II) Black Earth (*Brigalow Scrub*)							
10	Cotton planted early gives good yields; late planted, sometimes attacked by Corn Ear Worm	3.14	.271	*6.7*	15	80	33.9
11	Cotton 6 yrs. Fair crops	3.05	.324	*5.4*	19	70	46.3
12	Cotton sheds in drought, makes excessive growth with small yields in rains	2.11	.242	*5.0*	27	34	71.2
(III) Red Earth (*Soft Vine Scrub*)							
13	Cultivated 10 yrs. Maize 3 yrs. Cotton, first 2 crops good, last crop poor. Corn Ear Worm; Jassid	1.96	.242	*4.7*	5	98	24.7
14	Ditto. ditto. (Somewhat similar results)	1.55	.199	*4.5*	7	46	43.3
15	Maize and fodder, good crops; cotton poor ...	1.17	.155	*4.3*	7	(142)	(10.9)

* Available phosphate was determined on one per cent. citric acid extracts; the results have been converted to Truog values by dividing by 3.

† Available potash was also determined on one per cent. citric acid extract; the results have been converted to exchangeable potash values by multiplying by 2.

NOTE: The reason for converting the results is to render them suitable for comparison with data obtained by standard methods in vogue at the College.

The difference between the available phosphate and potash status of the different soil-types is also clearly marked by the analytical data in Table I, the Alluvial Soils being by far the richest in these mineral nutrients. There is a tendency for the nitrogen-potash ratio to show a characteristically low value (mean 4.5) for the Alluvial Soils and a high value (between 25 and 70) for the other two soil-types.

Bolting and Nitrate Status: In accordance with a previous conclusion, the bolting effect which is apparently associated with low carbon-nitrogen ratio of organic matter, was thought perhaps to be caused by excessive production of *soil nitrate*, since it is well known that the nitrogen component of soils having low carbon-nitrogen ratios is more rapidly nitrified than that of soils having high ratio values.* Some results obtained in nitrification studies, brought together in Table II, seem to substantiate this supposition.

The proportionate amount of nitrate in the fresh soil samples and the amounts developed when the soils are incubated under conditions favourable for nitrification tend to be relatively low for uncultivated grassland and for new cultivations as compared with old cultivations that have grown several cotton crops which tend more and more to develop the bolting habit. Further evidence in support of the contention that low yields, associated with bolting and insect damage, may be attributed to a relatively rapid rate of nitrification in soils belonging to certain specific types and in soils of the same type that have been cultivated for a relatively large number of years, will be presented below.

* Sir John Russell states in his book "Soil Conditions and Plant Growth", Sixth edition, 1932, p.313, that "nitrogen can appear as nitrate only if it exceeds a critical amount relative to the carbon, usually if the ratio is 12 or less". This value presumably applies to soils of temperate regions; for soils of regions where the climate is hot and moist, the critical value may be considerably lower than 12.

(II) Later Soil Studies

At the writer's suggestion, a special set of soil profile samples, representative of the main soil-types on which cotton is grown in Central Queensland, was collected under Mr. W. G. Wells' supervision during 1931 and shipped to Trinidad for laboratory examination by the customary routine methods in vogue in the Chemistry Department of the College. The soil samples were 56 in number, and were taken from 14 profile sites. The laboratory data obtained under the supervision of Mr. G. Rodrigues, Senior Analyst at the College, are set out in Table III, in which they are arranged under the chief soil-types. Brief notes on the main features of the sites, abstracted from the descriptive information supplied by agricultural officers and planters and forwarded to us by Mr. Wells, are also included in the table.

The profile spots mainly comprised pairs or sets of three contrasted sites where the cropping history differed; they consisted typically of one site in uncultivated land (forest, scrub or grassland) and one in cultivated land that had been under cotton for a variable number of years.

Unfortunately the soil samples were collected at irregular depths so that comparison of corresponding shallow layers is precluded. Accordingly, data for organic matter and nitrogen status have been recast and are set out in Table IV for the three layers, 0-6 inches, 6-12 inches and 12-24 inches approximate values for these regular depths being derived by interpolation on graphs constructed from the actual laboratory data. Weighted means for the full 5 foot-profiles are also included in Table IV.

Table II

Results of Nitrification Studies on Cotton Soils

Samples analysed in Queensland under direction of W. G. Wells, 1931

(Alluvial soil-type; Callide Experiment Station; Queensland)

Soil No.	Cropping	Fresh sample		Incubated samples				pH
		Total N %	NO_3 p.p.m.	days 14	28	42	56	
				NO_3 p.p.m.				
1	Grassland, not cultivated	0.121	0	3	5	5	8	7.0
2	New cultivation; cotton one year, previously grass	0.135	14	23	31	38	39	6.8
3	Old cultivation; cotton 6 yrs.; rank growth ...	0.127	19	23	30	42	43	6.9
4	Ditto ditto. previously grass ...	0.118	21	24	37	43	45	6.8
5	Ditto; cotton 2 yrs., fallow 2 yrs. ...	0.147	31	32	51	58	59	6.7

NOTE. (1) Values above 40 p.p.m. NO_3 would be regarded as relatively *high*, and values below about 20 p.p.m. NO_3 would be regarded as *low* (F.H.).
(2) Sampling depth stated to be 0-7 ins.

Discussion of Data (Tables III and IV). The following main results emerge from a scrutiny of the laboratory data in the last two tables.

(1) *Organic Matter Status.* There is not much difference in organic matter status between the three soil-types, except that the Alluvial Soils are deeper, maintaining fairly high organic matter contents down the profile, whereas the other soils show rapid diminutions below the top 6-inch layer.

(2) *Carbon-nitrogen Ratio.* The Alluvial Soil profiles exhibit much higher C/N ratios (mean for the whole profile, 11.0) than either the Black Earth profiles (mean 7.4) or the Red Earth profiles (mean 6.3). The high values are maintained to the 2-foot depth in the Alluvial profiles but fall off rapidly below the 1-foot depth in the others. These facts support the data pertaining to the three different soil-types for surface layers submitted by Mr. Wells and given in Table I.

Unfortunately, no *nitrate* data for the imported soils are available and no attempt was made by us to obtain any, since long storage in dry condition might have so altered the soil samples that nitrate values would have doubtful significance.

(3) *Reaction* is highly alkaline to about neutral in the upper 1½ to 2 feet of all the profiles except those of the Red Earth soil-type (Table III). The occurrence of calcium carbonate accumulations or of calcareous parent materials in the lower part of the alkaline profiles generally raises the pH figure to values over 8.0. The very highly acid reaction of the Red Earth profiles (except where basic ash left by bush burning has rendered the reaction of the surface layer temporarily alkaline) stands in marked contrast to the highly alkaline reaction of the profiles of the other two soil-types.

(4) *Available Phosphate Status* (Table III) is generally very high (values above 95 p.p.m.) especially in the Alluvial Soils. It is variable but high in the Black Earth but tends to be low in the Red Earth soils.

Notes on the Several Sites. The data for organic status provide further evidence of the relationship that appears to exist between carbon-nitrogen ratio and yielding capacity for cotton, since the sets of profile samples represent contrasted sites having different cropping history and varying reputation thus—

(i) *Callide Station*: The first three profiles refer to sites showing diminishing yields of cotton planted after grass. The least satisfactory site shows the lowest C/N ratio, though numerically the ratio is still relatively high (10.2).

Table III

Laboratory Data for Selected Soil Profile Samples Representative of Queensland Cotton Soils

Samples analysed at the Imperial College of Tropical Agriculture, Trinidad, under direction of G. Rodrigues, 1933

Profile No.	Name of planter and locality	Cropping and crop reputati n	Lr. Dpth. (ins.)	Total O.M. %	Total N %	C/N Ratio	Reaction (pH)	Avail. P_2O_5 (p.p.m.)
		(I) ALLUVIAL SOILS						
1	Callide Station (Biloela)	Cotton 5 yrs., after grass. Excellent yields for early plantings; 1800lb. ac. seed cotton	12	2.17	.11	11.3	7.1	342
			18	0.87	.06	8.3	7.3	
			42	0.77	.03	13.1	8.1	
			60	0.66	.03	12.8	8.3*	
2	Ditto	Cotton one year after grass. Good yields; 865 lb. ac. seed cotton	12	1.67	.09	10.8	7.1	231
			30	0.66	.04	9.3	7.8	
			42	0.81	.03	13.8	8.0	
			60	0.67	.03	13.8	8.1**	
3	Ditto	Cotton 5 yrs., after grass. Poor to only fair yields; variable growth. Boll shedding, severe Corn Ear Worm attack	18	1.51	.09	9.7	7.3	273
			30	0.53	.05	6.1	7.3	
			54	0.76	.05	8.2	7.9*	
			60	0.37	.03	6.3	7.9**	
4	M. Kircher (Mónal Creek, Upper Burnett)	Grassland ...	9	3.21	.16	11.4	7.3	396
			24	2.17	.10	12.1	7.9	
			60	1.42	.08	9.8	8.1	
5	Ditto	Cotton 6 yrs. Excellent yields at first (1800-2000 lb. ac.), diminishing in subsequent years	12	2.54	.13	11.4	7.5	339
			24	2.12	.12	10.7	7.8	
			39	1.38	.08	9.6	8.0	
			60	1.34	.08	9.4	8.1	

*= trace of Calcium carbonate (Concretionary accumulations).

**=fair to large amount of Calcium carbonate.

Table III—*Continued*

Laboratory Data for Selected Soil Profile Samples Representative of Queensland Cotton Soils

Samples analysed at the Imperial College of Tropical Agriculture, Trinidad, under direction of G. Rodrigues, 1933

Profile No.	Name of planter and locality	Cropping and crop reputation	Lr. Dpth. (ins)	Total O.M. %	Total N %	C/N Ratio	Reaction (pH)	Avail. P_2O_5 (p.p.m.)
		(II) Black Earth						
6	J. Cluff (Monal Creek, Upper Burnett)	Box forest, uncultivated lower slopes; grassland	4	4.21	.19	12.8	6.9	41
			28	0.62	.04	8.5	7.9**	
			60	0.21	.02	6.1	8.1*	
7	Ditto	Cotton 7 yrs. Site 20 ft. from last; previously Box forest lower slopes	5	0.79	.06	7.8	7.7	90
			17	0.59	.05	7.5	7.4	
			30	0.33	.02	9.0	8.3**	
			60	0.17	.03	3.7	8.3	
8	E. Bryant (Dululu)	Grass; Rhodes Grass. Scrub felled 13 yrs. ago	12	4.06	.29	8.3	7.3	107
			18	1.86	.11	9.8	7.3	
			30	0.89	.07	7.4	7.4	
			45	0.89	.05	9.8	7.7*	
			60	0.40	.03	7.8	8.3*	
9	Ditto	Cotton 7 yrs. Site 20 ft. from last	9	2.51	.18	8.1	7.5	181
			24	0.53	.05	6.4	6.5	
			30	0.50	.04	7.9	6.6	
			42	0.42	.03	7.1	7.9**	
			60	0.34	.02	8.3	8.3**	
10	W. Priddis (Dululu)	Grass; Rhodes Grass; original scrub felled 10 yrs. ago	10	2.87	.20	8.5	7.8	58
			18	1.43	.10	8.5	7.9	
			30	0.77	.08	5.8	8.0*	
			42	0.50	.07	4.9	8.2*	
			60	0.45	.07	3.7	8.3*	
11	Ditto	Cotton 10 yrs. Well farmed	12	2.77	.24	6.6	7.6	96
			24	2.15	.15	8.2	7.9*	
			42	0.42	.08	3.0	8.0*	
			60	0.78	.06	7.6	8.2**	
		(III) Red Earth						
12	Wruck (Mulgeldie, Upper Burnett)	Scrub-land; uncultivated; freshly burnt	15	2.40	.17	8.4	7.5	109
			36	0.67	.07	5.8	5.1	
			60	0.37	.04	4.9	4.6	
13	Coulston (Mulgeldie, Upper Burnett)	Grassland uncultivated; scrub burnt 2 yrs. ago	15	1.02	.10	6.1	4.4	2
			36	0.43	.04	5.6	4.1	
			60	0.33	.04	5.2	4.7	
14	Ditto	Cotton 5 yrs.; scrub previously burnt. Severe Jassid attack accompanied by boll shedding	15	2.62	.18	8.6	6.6	36
			36	0.55	.06	5.7	4.4	
			51	0.31	.04	4.1	4.1	
			60	0.36	.05	4.5	4.1	

*= trace of Calcium carbonate (Concretionary accumulations).

**= fair to large amount of Calcium carbonate.

(ii) *Kircher's Farm*: The paired profiles, Nos. 4 and 5, represent a grassland site and one nearby in cotton, that has shown diminishing yields accompanied by bolting in recent years. The organic status is somewhat poorer at the cotton site, and the C/N ratio tends to be lower but only in layers deeper than 6-inches (Table IV). The contrast in laboratory values here is not very marked.

(iii) *Cluff's Farm*: Here the organic status of the site several years in cotton is very much poorer than that in grass following Box forest. The top 6-inch layer of soil under grass contains four times as much organic matter as the cotton soil, and it also has a very much higher C/N ratio. The ratio for the cotton soil is rather low (6.5 in top 6-inch layer), and only poor yields of cotton would be expected. The note on this site unfortunately gives no hint as to its yielding capacity, however, so that no correlation can here be attempted.

(iv) *Bryant's Farm*: The first site under grass (profile No. 8), shows the highest organic status of any, the content of organic matter in the 6-inch layer being above 5 per cent. The C/N ratio for this layer is 8.1 and this medium-high value is maintained in the successive layers below. By contrast, the second site, under cotton, contains only about half as much organic matter but it has about the same C/N ratio (8.0 in the top 6-inch layer) though diminishing in layers below. The note on this site states that "variable results are obtained from cotton growing", and that "with a wet mid-season and late planting, severe Corn Ear Worm attacks (are) experienced, although the crop does not make excessive height or rank growth". Evidently the C/N ratio is not yet low enough for rapid production of nitrate.

(v) *Priddis' Farm*: The grassland site here (No. 10) contains the same amount of organic matter as the cotton site (No. 11) but its C/N ratio is distinctly higher in the layers down to 2 feet, though relatively not very high (8.3 in the top 6-inch layer). By contrast, the C/N ratio for the cotton soil is just below the suggested critical value, 7.0. This soil would therefore be expected to produce poor crops exhibiting bolting. The notes give no hint of this, however, beyond stating that "fairly good yields of cotton (are) usually obtained".

(vi) *Wruck's Farm*: The single profile from this area represents Red Earth soil from freshly-burnt soft Vine Scrub. Its organic status is good but the C/N ratio is somewhat low (8.8), though above the suggested critical value for cotton. The top soil is markedly alkaline (pH 7.5 in the first 15 inches; Table III), doubtless because of the presence of basic ash resulting from the burning. Below the soil is very acid.

It is stated that, following a good burn, very little weed growth occurs, and cotton gives good crops although after the first year, it is often attacked by Jassid and the crops are poor. On the other hand, excellent crops of maize can be grown for several years after felling and burning the scrub. Succeeding cotton, the land is usually planted in Rhodes Grass and grazed for four years before putting into cotton again.

Table IV

Data Recast to Aid Comparison of Profiles; Organic Matter and Nitrogen Status for Three Upper Layers

Prof. No.	Site (Owner of farm)	Crop yields	(1) Top 6" layer (0-6 ins.)			(2) Second 6" layer (6-12 ins.)			(3) Second foot layer (12-24 ins.)			(4) Whole Profile (0-60 ins.)		
			O.M. %	N %	C/N	O.M. %	N %	C/N	O.M. %	N %	C/N	O.M. %	N %	C/N
			(I) Alluvial Soils											
1	Callide Station	Excellent ...	2.9	.14	11.8	1.7	.09	11.4	1.0	.05	11.4	1.0	.05	11.9
2	Ditto ...	Good ...	2.0	.11	10.8	1.4	.08	10.6	1.0	.05	12.1	0.9	.05	11.4
3	Ditto ...	Fair ...	2.3	.12	10.9	1.7	.09	10.8	0.9	.07	8.0	1.1	.06	10.2
4	M. Kircher	(Grass) ...	3.4	.18	11.1	2.8	.13	12.3	2.1	.10	12.0	1.9	.10	11.1
5	Ditto ...	Falling ...	2.8	.14	11.4	2.4	.13	11.0	2.0	.11	10.9	1.7	.10	10.2
			(II) Black Earth											
6	J. Cluff ...	(Grass) ...	3.1	.18	10.1	1.3	.08	9.9	0.5	.04	8.2	0.6	.04	9.4
7	Ditto ...	Fair ...	0.8	.07	6.5	0.6	.07	5.5	0.4	.03	7.6	0.3	.03	5.9
8	E. Bryant ...	(Grass) ...	5.2	.37	8.1	3.2	.21	8.7	1.4	.11	7.3	1.5	.10	8.4
9	Ditto ...	Fair ...	2.9	.21	8.0	1.3	.09	7.8	0.5	.05	5.7	0.8	.06	7.8
10	W. Priddis ...	(Grass) ...	3.2	.22	8.3	2.1	.13	9.2	1.1	.09	7.0	1.1	.10	6.2
11	Ditto ...	Fair ...	3.2	.27	6.8	2.4	.21	6.5	1.5	.15	5.1	1.3	.12	6.4
			(III) Red Earth											
12	Wruck ...	(Burnt) ...	3.4	.22	8.8	2.2	.16	7.8	1.1	.10	6.3	1.0	.09	6.5
13	Coulston ...	(Grass) ...	1.3	.12	6.0	1.0	.09	6.3	0.5	.06	4.3	0.5	.06	5.6
14	Ditto ...	Poor ...	4.6	.23	8.9	2.5	.16	8.5	1.3	.09	8.3	1.0	.08	6.7

(vii) *Coulston's Farm*: The paired sets of profile samples comprise one set taken from grassland sampled two years after burning the scrub on Red Earth soil and the other taken from cotton land that had been under this crop for five successive years after scrub burning. The cotton soil samples still show the effect of basic ash in the upper layer in that its pH value is very much higher than that of the soil below, but the grassland soil samples do not show this effect at all, suggesting that considerable erosion took place following the felling and burning. This suggestion is supported by the much lower organic matter content of the top layer of the grassland soil, as well as by its abnormally low C/N ratio (6.3).

Carbon-nitrogen ratio is above the critical value in the cotton soil, but nevertheless boll shedding and Jassid damage are stated to have occurred. The ratio value is 8.9 in the top 6-inch layer which may perhaps be low enough to favour excessive nitrification.

(III) Recent Experience of Cotton-Growing in Queensland

Much additional experience has been gained in the growing of cotton in Queensland during the last 10 years since the work described in the last section was completed. Certain points of interest having particular bearing on the question of the carbon-nitrogen soil relationships of cotton might perhaps here be noted for the benefit of those who may be interested in the ecological aspects of cotton husbandry. Most of this additional information has been compiled from relevant articles and reports published in the bi-annual volumes of the *Queensland Agricultural Journal*, the *Annual Progress Reports from Experiment Stations*, and the *Reviews of the Work of the Experiment Stations*, issued by the Empire Cotton Growing Corporation in London.

(A) The "New Cultivation" Effect

The fact that new cotton cultivations do not usually show bolting has been attributed to a low rate of nitrate production depending on a high C/N ratio of the organic matter in the soil under the prevailing climate. Further proof of this has been sought by soil analysis at the Callide Experiment Station. In 1933-34, it was found that, after 8 successive years of cotton-growing on virgin alluvial clay-loam soil, both the carbon and the nitrogen contents of the soil had decreased significantly, but the C/N ratio was also greatly reduced. In 1934-35, however, it was found by analysis of soil samples collected in the midsummer rains that no significant difference could be detected in the nitrate content of soils that had been in cultivation to cotton for 3, for 6, or for 10 years, though higher values were obtained for the older cultivations. This may be explained by heavy leaching and by the fact that the nitrate contents of soil samples collected from among a growing crop (as these were) merely represent the residues which the plant is not able to absorb, and thus do not necessarily bear a positive relationship with the nitrate-producing capacity of the soil. During 1937-38, further nitrate determinations were made at various times in the winter months on soils where cotton had been growing continuously and where cotton succeeded cotton following 3 seasons of growth of Rhodes Grass. It was found that nitrate progressively increased from 6.1 to 10.5 p.p.m. in the case of continuous cotton, and from 0.25 to 5.5 p.p.m. in the second, indicating a lower nitrate status of the soil after grass.

Stated generally, when virgin forest soils or grassland are first brought into cotton cultivation, the nitrate-nitrogen content is below 12 p.p.m., whereas that of adjacent soils of 6 or 7 years old cultivations may be as high as 30 or 40 p.p.m. When samples of these diverse soils are incubated in the laboratory, those from new lands seldom give more than 30 p.p.m. whereas those from old cultivations may give up to 60 p.p.m. of nitrate-nitrogen.

Physical Effect: The decrease in organic matter which accompanies the increase in nitrate production is reflected in the physical deterioration of the soil structure, as a result of which the soil tends to compact under beating rain so as to become almost impenetrable to water. This necessitates careful tillage if improvement is to be effected by the use of implements.

(B) Factors Deciding Soil and Site Suitability

It was stated in the Introduction that most of the Queensland soils produce good crops of cotton during the first few years out of bush, but that subsequently the plants tend to bolt. The length of time that elapsed before bolting becomes evident varies greatly, depending on several factors of which fluctuating climate, time of planting, topographical site and soil-type are the chief.

(1) *Climate*: The climate of Queensland is very variable and most irregular. Rainfall in the cotton belt ranges from 22 to 35 inches a year (mean about 30 inches) and occurs mostly in the 3 summer months, January to March. Scattered showers and thunderstorms may also occur during late September and November. The chief features of the rainfall are its sporadic incidence and its tendency to fall in heavy showers, much being lost by surface run-off. The dry season extends from April to September. Day temperature rises during the spring and summer months (September to April) from about 50°F. to over 90°F. accompanied by decreasing humidity. Frosts in winter are rare. The temperature falls again during the autumn (April to June) as the dry season advances.

(2) *Time of Planting*: The ground is prepared for cotton-planting during the dry winter months, July to September. The uncertainty of the winter rains is the most disturbing factor in cotton-growing in Queensland. Unless adequate showers fall in early winter, the seed-bed may be too dry during October while the young plants are developing, and when drying winds desiccate the

soil. Early spring (September) planting is therefore advocated and seeds should be sown as soon as the soil has warmed up sufficiently to allow germination to take place. Late plantings (December or January) give unsatisfactory results, for the reason that the summer rains which soon follow produce succulent growths and favour vegetativeness rather than reproduction. The subsequent small crop of cotton bolls then tends to arise mostly on the terminal shoots and is subject to attack by Corn Ear Worm.

(3) *Topography*: Drainage impedence, induced by depressed topography, creates moist subsoil conditions which accentuate the effects of summer rainfall so that late-planted crops are likely to yield still less on low-lying sites. On the other hand, hill slopes and river levees (particularly where the soil is open-structured or underlain by gravel) favour late plantings, even in seasons of unusually heavy rain.

(4) *Soil-Type*: (i) Undoubtedly the *Red-Earth* soils are least suited to cotton-growing in Queensland, although they may do well during the first two years after the scrub has been cleared and burnt, especially with late plantings and in wet years. This is because their natural structure is open and porous, their topography is sloping or elevated, and their content of nutrient-rich organic matter, having suitably high carbon-nitrogen ratio, is relatively big. Later, however, they deteriorate rapidly and cotton crops not only tend to bolt as the C/N ratio falls, but their actual growth diminishes, partly through loss of humic surface soil by erosion and partly because of the inherent low available phosphate and potash status which characterises this soil-type.

(ii) By contrast, certain phases of *Alluvial Soils* appear to be ideally suited to cotton-growing by virtue of their loamy texture and readily-infilterable though retentive structure, their slightly elevated topography on river banks or levees, giving depth and free drainage, their high mineral nutrient status (especially with respect to potash and phosphate), and their large content of deeply-penetrating organic matter having high C/N ratio, giving balanced nutrition between nitrogen, phosphate and potash. Other phases of Alluvial Soils may not be so satisfactory either because of a clayey texture and impervious structure, or of the presence of hard-pan not far below the surface or depressed topography, even though their mineral-nutrient and organic status may be high. The low-lying clayey phases are more satisfactory when the spring rains are inadequate in amount, since their initial content of subsoil moisture may then suffice to meet the needs of the developing crop until the summer rains arrive.

(iii) On general evidence, the *Black Earth* soils appear to be intermediate between the other two major soil-types. Their open pervious structure and their elevated topography favour good drainage, so that, provided the nutrient status and the organic matter content are satisfactory, these soils should yield good cotton crops for many years when the weather is favourable.

(5) *Importance of Subsoil Moisture*: A good supply of soil moisture in the upper 18 to 24 inches is necessary for successful cotton-growing in Queensland. It helps the crop to tide over periods of inadequate rainfall and to withstand heat waves. The method of preparation of the seed-bed is thus particularly important. There is usually no shortage of subsoil moisture with cotton planted on newly-cleared land or on old cultivated land that has been in clean-fallow or grass-fallow or under a shallow-rooted summer fodder crop. Otherwise, the land ought to be ploughed in autumn in order not only to "deepen" it but also to produce a granular surface of suitable infiltrability so that the winter rains will easily penetrate. The ploughing also helps to conserve the late summer rainfalls.

(6) *Value of Rotations*: Rotations of sorghums and cotton, Panicums and cotton, and maize and cotton, have proved to be very suitable for the rich *alluvial soils*. For poor alluvial soils and forested-slopes soils, rotations including leguminous crops, such as cowpeas, with grain or fodder-grass crops are preferable. Above all, Rhodes Grass (*Chloris guayana*) grown *three or four years* in succession, has been found to be a most suitable preparation for cotton, especially in good alluvial soils. After breaking up the grassland, cotton may then be grown for two years separated by a year of maize or Panicums, and the land then put back again into Rhodes Grass for three years more and the whole cycle repeated.

(7) *Significance of New Cotton Varieties*: The differences in fertility between old and new cotton cultivations and between different soil-types that were early demonstrated to occur in Queensland suggested the possibility of employing a wide range of cotton varieties to suit the differing conditions. Hard-bodied cottons were accordingly imported and a series of "variety testing trials" was inaugurated in different districts. It was found that hard-bodied cottons do best on the poorer compacted soils whereas softer-bodied cottons are more suited to the rich alluvial soils producing relatively large amounts of nitrate. The varieties grown are all of the *Gossypium hirsutum* type which includes American Upland cottons: these are believed to be the most suitable for commercial growing in Queensland. A wide range of approved varieties is now available for planting in different districts.

(8) *Advantages of Irrigation*: The liability of the cotton-crop in Queensland to arrested growth during hot dry periods is a frequent reason for poor yields. The latest development in cotton husbandry in Queensland is therefore the increasing attention given to irrigation. Not all lands are suitable to furrow irrigation, however, so that the spray method is being tried in experimental areas with very promising results.

Conclusions

The introduction of appropriate rotations involving long-term grass leys suppresses the incidence of bolting in cotton-crops grown on suitable land in Queensland. The effect of the grass is undoubtedly the maintenance of a good supply of soil organic matter having a high carbon-nitrogen ratio so that excessive production of nitrate is prevented except during unusually rainy weather. The use of long-term grass rotations and of rotations involving grain and fodder grasses has gone a long way toward the establishment of a sound agriculture system. It has furthermore enabled the farmer to combine cotton-growing with dairying; this kind of mixed farming may eventually solve the economic problems associated with the cotton soils of Queensland.

Summary

1. This article first presents results of laboratory analysis of representative samples examined both in Queensland and at the College of some typical Queensland soils supporting cotton-plants prone to "*bolting*" that is, to the development of unfruitful, rank, sappy growths particularly susceptible to insect attack.

2. It was found that the soils producing bolting plants are characterised by relatively *low carbon-nitrogen ratios*, whereas those supporting normal fruitful plants show high carbon-nitrogen ratios over a wide range of organic matter contents. The critical C/N ratio value seems to lie between 7.0 and 8.5.

3. Satisfactory, high-ratio cotton soils in Queensland are mostly rich *Alluvial* soils and unsatisfactory low-ratio soils are *Red Earth* soils. *Black Earth* soils are intermediate. These three soil-groups comprise most of the Queensland cotton lands, both actual and potential.

4. Bolting of cotton has been shown to be a physiological phenomenon associated with *high rates of nitrate production* in the soil which is a feature of low C/N ratio soils under certain moisture conditions.

   On incubation in the laboratory, low-ratio cotton soils associated with bolting give values for nitrate-nitrogen up to 60 p.p.m., whereas high-ratio, normal soils seldom give values more than 30 p.p.m.

5. A striking feature of cotton soils in Queensland is the "*new land*" or "*new cultivation*" effect which is manifest in the early cotton crops not showing bolting and giving satisfactory yields, whereas the later crops show the phenomenon increasingly during successive croppings. The cause of this effect has also been traced to high C/N ratio in soil newly brought in from forest or bush, and this is again associated with a low rate of nitrate production.

   Furthermore, land that has been in grass for several years following many successive crops of cotton which have given diminishing yields through bolting, is capable of supporting satisfactory crops without bolting when again brought into cultivation, for the same reason.

6. Many factors therefore decide the suitability of the soil and the site for successful cotton-growing in Queensland, among which the following are the chief, and are discussed in turn in the article.

   (i) The *climate* of Queensland is extremely variable and undependable. Heavy showers, heat-waves, intense droughts and occasional frosts adversely influence yields.

   (ii) The best *planting date* is early spring (September in Queensland); winter rains are chiefly relied on to give adequate soil moisture for seedling growth.

   (iii) The most suitable *topography* is that which tends to maintain adequate but not excessive soil moisture during the early stages of plant development. This partly depends also on profile features which differ in different soil-types. Thus some flat-land alluvial soils suffer from drainage impedence through the presence of hard-pan or lime accumulations and may thus be too wet in rainy years.

   (iv) The best *soil-type* is Alluvial, provided it is a well-drained, loamy phase.

   (v) *Subsoil moisture* may be partly controlled by tillage.

   (vi) The best *rotations* include 3 or 4 years Rhodes Grass followed by two years cotton separated by a grain crop such as maize or Panicums.

   (vii) A range of *cotton varieties* (America Upland type) has been bred to suit different environmental conditions.

   (viii) *Irrigation*, both supplementary furrow irrigation and spray irrigation, is being experimentally investigated.

It is intended in the next article to attempt to apply the results and findings regarding the carbon-nitrogen relationships of cotton soils in Queensland to conditions obtaining in the British West Indies cotton-growing islands.

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THE COLLEGE PERMANENT MANURIAL EXPERIMENT—*Continued*

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(I) Introduction

THE initiation of this experiment on Field 8 of the College Farm and its main objects have been already described in this *Journal* (1941, Vol. XVIII, No. 3, pp.48-61). The soil was limed and the manurial treatments were first applied in January, 1931, soon after the plots had been sampled for soil examination. The plots were again soil-sampled in January, 1937, exactly 6 years after their initiation. The article cited above gave a full account of the changes that had gone on in the soil of the plots as a result of the liming and manuring and the continuous cropping of the land with a range of short-period crops, comprising maize, cotton, tobacco, hill-rice, millet, broom-corn, soya-bean, sunnhemp, kidney-bean and sword-bean, grown in rotation and occasionally with irrigation in dry weather. On the average, three crops were grown to maturity each year.

Subsequent to the soil examination in January 1937, modified treatments were worked out so as more accurately to allow of a qualitative comparison between organic manure (pen manure with compost) and approximately chemically-equivalent inorganic manures, since it had been demonstrated that the original treatments were unbalanced with regard to chemical composition. The modified treatments were first applied in 1941. The liming proved to have been excessive; consequently no more lime has been applied since the beginning of the experiment in 1931.

(II) Lay-Out and Treatments

The original lay-out consisted of 16 rectangular plots, each 1/20 acre in area, arranged in two ranks, and separated by earth bunds about 1 1/2 feet high. (See Diagram I in the first paper).

The original manurial treatments were:—

Plot 4: Control; no manure

(A) ARTIFICIAL SERIES
Plot 5: Nitrogen *plus* phosphate (NP)
Plot 6: Nitrogen *plus* potash (NK)
Plot 7: Phosphate *plus* potash (PK)
Plot 8: Nitrogen *plus* phosphate *plus* potash (NPK)

(B) LIME SERIES
Plot 12: Lime alone (L)
Plot 13: Lime *plus* nitrogen *plus* phosphate (LNP)
Plot 14: Lime *plus* nitrogen *plus* potash (LNK)
Plot 15: Lime *plus* phosphate *plus* potash (LPK)
Plot 16: Lime *plus* nitrogen *plus* phosphate *plus* potash (LNPK)

(C) ORGANIC SERIES
Plot 3: Organic manure alone (O)
Plot 11: Organic *plus* lime (OL)
Plot 9: Organic *plus* lime *plus* nitrogen *plus* phosphate (OLNP)
Plot 1: Organic *plus* lime *plus* nitrogen *plus* potash (OLNK)
Plot 10: Organic *plus* lime *plus* phosphate *plus* potash (OLPK)
Plot 2: Organic *plus* lime *plus* nitrogen *plus* phosphate *plus* potash (OLNPK)

UNIT DRESSINGS

The unit dressings of artificial manures applied during the first 6-years period were:—

Nitrogen (N): Sulphate of ammonia (20 per cent.), 110 lb. ac.
Phosphate (P): Superphosphate (18 per cent.), 176 lb. ac.
Potash (K): Sulphate of potash (52 per cent.), 55 lb. ac.

Lime was initially applied to ten of the plots at the rate of 10 tons ground limestone per acre, in one dressing.

Organic manure, consisting of a mixture of pen manure and compost, was applied at the rate of 10 tons per acre, reduced after 2 years to 5 tons per acre, to each and every crop.

The modified treatments (unit dressings), first applied in 1941, and applied thereafter before each crop was sown or planted, are given below. They are based on approximate *potash equivalence* between the dressings of inorganic artificial manures and the grade of organic manure that is available for application at the College Farm.

(1) *Organic Manure*:—Pen manure, containing approximately 17 per cent. of total organic matter, 0.46 per cent. of total nitrogen, 0.28 of total phosphate and 0.70 per cent. of total potash. Rate of application, 5 tons per acre or 560 lb. per plot applied before each crop.

(2) *Artificial Manures*:—

Sulphate of Ammonia, containing 20 per cent. nitrogen; 3 cwt. per acre or 17 lb. per plot, applied generally twice a year, *equals* 6 cwt. per acre per year, or 34 lb. per plot per year.

Superphosphate, containing 18 per cent. of water-soluble phosphate; 2 cwt. per acre, or 11 lb. per plot, twice a year, equals 4 cwt. per acre, or 22 lb. per plot per year.

Sulphate of Potash, containing 52 per cent. potash; 1½ cwt. per acre, or 7½ lb. per plot, twice a year, or generally, 2 2/3 cwt. per acre, or 15 lb. per plot per year.

(3) *Lime*:—No more will be applied until all the lime reserves from the initial excessive dressing of 10 tons per acre (10 cwt. per plot) have disappeared.

NOTE: (1) The magnitude of the new dressing of 5 tons pen manure is the same as that which has been applied since 1933.

(2) The new dressing of sulphate of ammonia is a little more than twice the original dressing.

(3) The new dressing of superphosphate is about the same as that of the original dressing.

(4) The new dressing of sulphate of potash is nearly twice the original dressing.

(III) Crop Responses

During the first seven years of the experiment, eighteen crops were grown and the responses of these crops to the different manurial treatments were discussed in the first paper (*ibid*: pp.48-51). It is proposed to examine here the behaviour of the ten crops grown subsequently to the first eighteen; these ten crops were grown over a period of 5½ years, between October, 1937, and May, 1943. A table of the crops grown and the recorded plot yields, expressed in pounds per acre, is given in the *Appendix*. In some cases records were taken of the yield both of grain and straw, and in these cases two values are shown for each crop for each plot, (G) indicating grain or seed or pod yields and (S) straw or leaf-and-stem yields. In the case of sweet potatoes, separate records were taken of tubers (T) and vines (V). It should be noted that the yields of Crops 27 and 28 were obtained from half-plots, each only one-fortieth of an acre in area. It should be noted also that, although the yields of the Yam crop, No. 26, and of the Bengal Bean crop, No. 28, are included in the appendix for the sake of completeness, the figures have little value. The Yam crop, in common with the majority of the yams planted in the neighbourhood in 1941, was a failure; planting was delayed on account of very wet weather, and there was a period of drought subsequent to planting which made it impossible to establish the crop. In the case of the Bengal Bean crop, the growth was patchy on all plots, and there was such disparity of plant population per plot and such unevenness of maturity at harvest that plot yield figures are considered unreliable. In the following tables, in which the comparative plot values for each crop are set out, the values for the Yam and Bengal Bean crops have been omitted.

(1) Response to Liming

In Table I the comparative crop yields of Plot 4 (receiving neither lime, nor artificial nor organic manures) and Plot 12 (receiving lime, but no manures) are set out; the yields of Plot 4 (unlimed) have been reduced in each case to 100 (see Column 1), and the yields of Plot 12 (limed) (Column 2) are shown as percentages of the control plot figures. It will be seen that liming appears to have been responsible for slight decreases in yield in eight instances, a marked decrease in the yield of Woolly Pyrol (Crop 23), and slight increases in four instances. The differences are, however, small and may be due to chance.

Of the pair of plots receiving organic manure but no artificial, (see Table I, Columns 3 and 4), the limed plot gave higher yields than the unlimed plot in only three instances, (both Maize crops, Nos. 21 and 27), but lower yields than the unlimed plot for all other crops.

Table I

Comparative Yield Data of Limed and Unlimed Plots

Crop No.	Crop	Plot 4 No Manures No Lime	Plot 12 No Manures Lime	Plot 3 Organic No Artificials No Lime	Plot 11 Organic No Artificials Lime	Plots 5, 6, 7, 8 Artificials No Organic No Lime	Plots 13, 14, 15, 16 Artificials No Organic Lime
19	Maize (G)	100	92	100	79	100	85
	Maize (S)	100	91	100	66	100	113
20	Sorghum	100	111	100	78	100	121
21	Maize (G)	100	89	100	103	100	111
	Maize (S)	100	94	100	94	100	102
22	Canavalia (G)	100	89	100	54	100	99
	Canavalia (S)	100	117	100	74	100	110
23	Woolly Pyrol	100	39	100	77	100	114
24	Sweet Potato (T)	100	100	100	88	100	98
	Sweet Potato (V)	100	93	100	56	100	48
25	Sugar Cane	100	103	100	93	100	110
26	Yams	—	—	—	—	—	—
27	Maize (G)	100	70	100	114	100	89
	Maize (S)	100	85	100	107	100	113
28	Bengal Bean (G)	—	—	—	—	—	—
	Bengal Bean (S)	—	—	—	—	—	—

Where artificial manures were used without organic manures, the addition of lime has resulted in small increases in yield over similarly manured but unlimed plots in some instances, and small decreases in others (compare columns 5 and 6, Table I).

These results confirm what appeared from examination of the crop yields of the first period of the experiment, namely that liming seems not to have had any beneficial effect.

(2) Manurial Constituents

(*a*) *Potash*: In Table II comparison is made of plots receiving artificial manures, but no organic manure and no lime, with Plot 4 which received no manure of any kind and no lime. In Table III comparison is made of plots receiving artificial manures and lime, but no organic manures, with Plot 12 which received lime but no manures of any kind. In the case of the unlimed plots (Table II), the plot which received nitrogen and phosphate

Table II

Comparative Yield Data of Unlimed Plots

Crop No	Crop	Plot 4 No Lime No Manure	Plot 5 No Lime NP (Lacking K)	Plot 6 No Lime NK (Lacking P)	Plot 7 No Lime PK (Lacking N)	Plot 8 No Lime NPK (Complete)	Plot 3 No Lime Organic
19	Maize (G)	100	117	174	112	140	200
	Maize (S)	100	101	172	119	142	234
20	Sorghum	100	118	175	110	168	241
21	Maize (G)	100	58	253	142	163	276
	Maize (S)	100	72	194	183	217	239
22	Canavalia (G)	100	62	137	131	152	286
	Canavalia (S)	100	62	85	85	98	203
23	Woolly Pyrol	100	5	178	304	127	298
24	Sweet Potato (T) ...	100	80	365	361	257	653
	Sweet Potato (V) ...	100	129	267	178	180	461
25	Sugar Cane	100	83	140	124	139	214
26	Yams	—	—	—	—	—	—
27	Maize (G)	100	119	170	94	130	166
	Maize (S)	100	106	176	133	181	185
28	Bengal Bean (G) ...	—	—	—	—	—	—
	Bengal Bean (S) ...	—	—	—	—	—	—

Table III

Comparative Yield Data of Limed Plots

Crop No.	Crop	Plot 12 Lime No Manure	Plot 13 Lime NP (Lacking K)	Plot 14 Lime NK (Lacking P)	Plot 15 Lime PK (Lacking N)	Plot 16 Lime NPK (Complete)	Plot 11 Lime Organic
19	Maize (G)	100	106	141	94	155	172
	Maize (S)	100	131	187	153	196	171
20	Sorghum	100	149	163	127	184	168
21	Maize (G)	100	79	244	182	259	318
	Maize (S)	100	92	231	192	207	238
22	Canavalia (G)	100	92	119	156	168	174
	Canavalia (S)	100	107	57	71	74	129
23	Woolly Pyrol	100	112	712	453	523	593
24	Sweet Potato (T) ...	100	69	176	192	214	571
	Sweet Potato (V) ...	100	73	136	117	197	288
25	Sugar Cane	100	110	137	129	141	193
26	Yams	—	—	—	—	—	—
27	Maize (G)	100	182	165	124	162	262
	Maize (S)	100	161	234	178	224	234
28	Bengal Bean (G) ...	—	—	—	—	—	—
	Bengal Bean (S) ...	—	—	—	—	—	—

but lacked potash (Column 2), gave slight increases in yield over the control plot (Column 1) in six instances, but in only one case did these increases exceed 20 per cent.; in seven instances the potash-lacking treatment gave yields noticeably lower than the control, and in four of these instances the yields were about 40 per cent. less than the control plot yields. In the presence of lime, however, (Table III), the lack of potash was apparently less harmful, on the whole, although the plot yields for the potash-lacking plot in the case of the sweet potato crop were about 30 per cent. less than the control plot yields.

Reference to Tables IV and V, in which the several incomplete artificial dressings are compared with the complete dressing, shows that the omission of potash (Column 3) from the complete dressing of artificials, whether in the presence or absence of lime, has resulted in very serious decreases in yield in practically every case.

These results indicate that potash is a limiting factor to crop production on College Farm soils.

(*b*) *Phosphate*: Where only artificial nitrogen and potash are applied, the lack of phosphate, whether in the presence or absence of lime, has not

Table IV

Comparison of Complete Fertiliser Treatment with Incomplete Treatments on Unlimed Plots

Crop No.	Crop	Plot 8 No Lime No Organic NPK (Complete)	Plot 4 No Lime No Organic No Artificials (Lacking NPK)	Plot 5 No Lime No Organic NP (Lacking K)	Plot 6 No Lime No Organic NK (Lacking P)	Plot 7 No Lime No Organic PK (Lacking N)
19	Maize (G)	100	71	84	124	80
	Maize (S)	100	71	72	122	84
20	Sorghum	100	59	70	104	65
21	Maize (G)	100	61	35	155	87
	Maize (S)	100	46	33	90	84
22	Canavalia (G)	100	66	41	90	86
	Canavalia (S)	100	102	63	86	86
23	Woolly Pyrol	100	79	4	140	239
24	Sweet Potato (T)	100	39	31	142	140
	Sweet Potato (V)	100	56	72	148	99
25	Sugar Cane	100	72	60	101	89
26	Yams	—	—	—	—	—
27	Maize (G)	100	77	92	131	72
	Maize (S)	100	55	58	97	74
28	Bengal Bean (G)	—	—	—	—	—
	Bengal Bean (S)	—	—	—	—	—

Table V

Comparison of Complete Fertiliser Treatment with Incomplete Treatments on Limed Plots

Crop No.	Crop	Plot 16 Lime No Organic NPK (Complete)	Plot 12 Lime No Organic No Artificials (Lacking NPK)	Plot 13 Lime No Organic NP (Lacking K)	Plot 14 Lime No Organic NK (Lacking P)	Plot 15 Lime No Organic PK (Lacking N)
19	Maize (G)	100	64	68	91	61
	Maize (S)	100	51	67	95	78
20	Sorghum	100	54	81	89	69
21	Maize (G)	100	39	31	94	70
	Maize (S)	100	48	44	111	93
22	Canavalia (G)	100	60	55	71	93
	Canavalia (S)	100	135	144	77	96
23	Woolly Pyrol	100	19	21	136	87
24	Sweet Potato (T)	100	47	32	82	90
	Sweet Potato (V)	100	51	37	69	59
25	Sugar Cane	100	71	78	97	92
26	Yams	—	—	—	—	—
27	Maize (G)	100	62	113	102	76
	Maize (S)	100	45	72	104	79
28	Bengal Bean (G)	—	—	—	—	—
	Bengal Bean (S)	—	—	—	—	—

been harmful (compare columns 3 and 1, Tables II and III); the plots lacking phosphate gave very much higher yields than the control plots, which received no manure, in all cases except that of Crop 22 (Canavalia haulm). Reference to Table IV (*see* Columns 1 and 4) discloses the interesting fact that, in the absence of lime, the omission of phosphate from the complete mineral dressing appears even to have been beneficial; Plot 6, which received only artificial nitrogen and potash, gave on the whole higher yields than Plot 8 which received nitrogen, potash and phosphate. The same result, however, did not occur in the presence of lime (*see* Table V); in this case the omission of phosphate from the complete mineral dressing on the limed plots has resulted in slight (11 per cent. or less) decreases in five instances, decreases of from 18 to 31 per cent. in four instances, and rather small increases in four instances (compare Columns 1 and 4, Table V).

These results indicate that phosphate deficiency is not likely to occur on College Farm soils, and point to the general inutility of phosphate manuring here.

(*c*) *Nitrogen*: Lack of nitrogen appears to be more serious than lack of phosphate, but not nearly so serious as lack of potash (Tables II and III, Columns 1-5). Reference to Table IV shows that, in the absence of lime, the omission of nitrogen from the complete dressing resulted in loss in yield in all except two cases; but that the losses in yield, compared with the unlimed plot receiving complete mineral dressing, exceeded 25 per cent. in only three cases (compare Columns 1 and 5). In the presence of lime, (Table V, Columns 1 and 5) the omission of nitrogen resulted in losses of more than 25 per cent. in only four cases, and in losses less than 25 per cent. in all other cases.

The omission of nitrogen from the complete dressing seems, in fact, to have not nearly so serious a result as might be expected, in view of the fact that all crops grown under local conditions are generally supposed to respond greatly to manuring with nitrogenous artificial fertilisers.

(3) Comparison of Organic With Inorganic Manures

Plots receiving organic manure but no artificials gave very considerably higher yields than the control (no manure) plots, in both the presence and absence of lime (Tables II and III, Columns 6 and 1). Comparison of yields of Plot 3, which received organic manure but no artificials and no lime, with yields of Plot 8, which received the complete artificial dressing but no organic and no lime (*see* Table VI, Columns 1 and 2), shows that the organic manure produced higher yields than the inorganic in all cases. Reference to Table VI (Columns 3 and 4) shows that the same result occurred where lime was present, although, here in two cases the artificials slightly outyielded the organic. It would seem, therefore, that either the amounts of nutrients supplied in the artificial dressing are still less than the amounts of the nutrients present in the organic dressing; or else that the organic manure has some value not assessable merely in terms of the plant nutrients which it contains.

Table VI

Comparison of Organic with Inorganic Treatments

Crop No.	Crop	Plot 8 No Lime Artificials (NPK) No Organic	Plot 3 No Lime No Artificials Organic	Plot 16 Lime Artificials (NPK) No Organic	Plot 11 Lime No Artificials Organic	Plot 2 Lime NPK Organic	Plots 13, 14, 15, 16 Artificials No Organic Lime	Plots 1, 2, 9, 10 Artificials Organic Lime
19	Maize (G) ...	100	143	100	111	154	100	181
	Maize (S) ...	100	165	100	87	163	100	160
20	Sorghum ...	100	143	100	92	134	100	141
21	Maize (G) ...	100	164	100	123	109	100	146
	Maize (S) ...	100	110	100	115	161	100	160
22	Canavalia (G)	100	188	100	115	225	100	215
	Canavalia (S) ...	100	207	100	173	369	100	290
23	Woolly Pyrol ...	100	235	100	113	163	100	141
24	Sweet Potato (T)	100	254	100	267	348	100	246
	Sweet Potato (V)	100	256	100	146	373	100	517
25	Sugar Cane ...	100	155	100	137	170	100	157
26	Yams	—	—	—	—	—	—	—
27	Maize (G) ...	100	128	100	162	207	100	178
	Maize (S) ...	100	102	100	104	148	100	133
28	Bengal Bean (G)	—	—	—	—	—	—	—
	Bengal Bean (S)	—	—	—	—	—	—	—

(4) Use of Artificial and Organic Manures Together

As might be expected, the use of both artificial and organic manures together produces higher yields than when either is used in the absence of the other (compare Columns 3, 4 and 5; and Columns 6 and 7, Table VI).

The plot producing the highest yields throughout the experiment (*see* Appendix) was Plot 2 which received the complete mineral mixture in addition to organic manure and lime. Reference to Table VII suggests that where organic manure has been supplemented by artificials, the omission of nitrogen from the mineral mixture has resulted in some loss in yield (compare Columns 4 and 5); the omission of artificial phosphate has been less important than the omission of nitrogen (Columns 3, 4, 5); while the omission of potash from the mineral dressing (Column 2) has resulted not only in yields smaller than those produced by the complete mineral dressing (Column 5), but in some cases in yields no better than those obtained when organic manure was used alone, without any supplementary artificials at all (Column 1). (It should be noted that in all plots in this experiment where artificials were used in conjunction with organic manures, lime was also used).

(5) Conclusions

From the results detailed above the following are the main conclusions :—

(i) The original lime dressing, as was noted in the first seven years of the experiment, has not had any beneficial effect on crop yields.

(ii) Where organic manure is used without inorganic manures, the lime appears to have exerted a depressing effect.

(iii) Where artificials are used in the absence of organic manure the effect of lime has been variable, producing increases in yield in some cases and decreases in others.

(iv) Deficiency of potash is the most important limiting factor (so far as nutrients are concerned) to crop production on College Farm soils. Omission of potash from the dressings of artificial manures, whether these are applied alone or in conjunction with organic manures, results in very appreciable loss in yield.

(v) Phosphate deficiency is not likely to occur here, and inclusion of phosphate in manurial dressings has on the whole given disappointing results.

(vi) Although lack of nitrogen appears more serious than lack of phosphate, yet losses due to the omission of nitrogen from the mineral mixture have been surprisingly small, having regard to the supposed importance of nitrogenous manures in local farming practice.

(vii) Comparison of organic with inorganic manure shows that the former has produced higher yields than the latter. It seems possible, therefore, that the organic dressing still possesses more than the equivalent amount of plant nutrients contained in the inorganic dressing; or that the value of the organic manure does not lie only in its content of plant nutrients.

(viii) Where both organic and artificial manures are applied together, the best results are obtained when a complete artificial dressing is applied in conjunction with the organic. Omission of potash from the artificial dressing used to supplement the organic manure is unwise.

Table VII

Comparison Yield Data for Limed Plots Receiving Artificials in Addition to Organic Manure

Crop No.	Crop	Plot 11 Organic Lime No Artificials	Plot 9 Organic Lime NP (K omitted)		Plot 1 Organic Lime NK (P omitted)		Plot 10 Organic Lime PK (N omitted)		Plot 2 Organic Lime NPK (Complete)	
19	Maize (G)	100	143		115		125		139	
	Maize (S)	100	164		163		108		187	
20	Sorghum	100	145		128		104		146	
21	Maize (G)	100		86		82		94		89
	Maize (S)	100		98	129		118		140	
22	Canavalia (G)	100	147		145		153		218	
	Canavalia (S) ...	100		87	222		173		213	
23	Woolly Pyrol ...	100		61	114		109		144	
24	Sweet Potato (T) ...	100		80	105		130		130	
	Sweet Potato (V) ...	100	152		163		164		256	
25	Sugar Cane	100		92		94	109		124	
26	Yams	—		—		—	—		—	
27	Maize (G)	100	110		100			91	128	
	Maize (S)	100	119		109		104		142	
28	Bengal Bean (G) ...	—	—		—		—		—	
	Bengal Bean (S) ...	—	—		—		—		—	

(IV) Nutrient Relationships

The soil of the plots was sampled for the third time near the end of the 1943 dry season, *i.e.*, on 31st May, 1943, about 6 years after the last sampling, and 12 years after the first sampling. The samples comprised 10-spot composites taken to a depth of 6 inches. The results of their analysis by routine methods employed in the Chemistry Department of the College are presented in part in Table VIII, in which are also set out comparable data for the original sampling and for that performed at the end of the first 6 year period.

(1) Discussion of Laboratory Data

From a study of the tabulated data obtained by soil analysis, the following main changes have apparently taken place in the original soil comprising the experimental area as a result of manurial treatment and liming and continual cropping after a total period of 12 years' duration.

(*a*) *Soil Reaction* :—The acidity of Control Plot (no manure) has decreased considerably as a result of the continuous cropping. The effect of liming is now diminishing markedly on the limed

Table VIII

Laboratory Data showing Comparison of Nutrient Status of Plot-Soils before and after Manurial Treatment and Cropping for Two Consecutive Six-Year Periods

(Surface 6-inch layer)

Treatment	Reaction Norm. pH			O.M. %			N %			C/N Ratio			P_2O_5 p.p.m.			K_2O p.p.m.		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Control ...	6.1	6.7	6.9	1.71	1.46	1.42	.13	.11	.11	7.8	7.6	7.3	39	24	23	40	82	31
Lime ...	6.0	8.1	7.4	1.78	1.37	1.27	.13	.11	.10	7.7	7.5	7.4	28	49	32	58	67	40
O.M. ...	6.2	7.3	7.3	1.74	1.74	2.45	.13	.13	.14	7.6	7.9	9.9	49	82	49	73	110	71
Lime+O.M.	6.4	8.0	7.8	1.70	2.02	1.78	.13	.13	.13	7.8	8.9	8.0	49	141	110	69	141	54
Artificials																		
NP ...	6.2	5.8	5.7	1.76	1.61	1.38	.13	.12	.10	7.6	8.0	7.9	50	37	46	50	62	33
NK ...	6.2	5.7	5.0	1.73	1.66	1.40	.13	.11	.11	7.6	8.7	6.6	60	18	24	57	90	74
PK ...	6.1	6.7	6.7	1.70	1.76	1.69	.14	.14	.13	7.1	7.7	7.2	38	51	58	49	93	67
NPK ...	6.4	6.1	5.6	1.64	1.82	1.49	.13	.13	.13	7.1	8.3	6.9	35	40	44	37	87	59
Lime+Artificials																		
L.NP ...	6.0	8.0	7.4	1.73	1.46	1.51	.13	.11	.12	7.7	7.3	7.4	33	111	82	46	63	40
L.NK ...	6.0	8.1	7.3	1.90	1.47	1.36	.13	.11	.11	7.8	7.2	7.0	34	49	34	75	75	95
L.PK ...	6.0	8.2	7.2	1.73	1.55	1.53	.13	.11	.12	7.7	7.8	7.4	24	98	154	69	84	103
L.NPK ...	5.9	8.1	7.3	1.74	1.74	1.60	.13	.11	.13	7.6	8.8	6.9	27	118	76	62	98	89
Organic+Lime+Artificials																		
O.L.NP ...	6.6	7.7	7.7	2.05	2.27	2.09	.14	.14	.15	8.3	8.9	8.2	(114)	235	340	48	148	65
O.L.NK ...	6.2	7.8	7.4	1.71	2.27	2.27	.13	.14	.15	7.8	9.2	8.8	60	157	81	62	178	102
O.L.PK ...	6.3	7.8	7.3	1.64	2.00	2.13	.12	.13	.14	8.1	8.8	8.7	45	231	360	69	170	163
O.L.NPK	6.2	7.5	7.6	1.88	2.18	2.22	.13	.14	.15	8.5	9.0	8.4	50	180	275	64	148	108
Means (16) of all	No Lime 6.2	(6.4)	(6.2)	1.76	1.77	1.73	.13	.12	.13	7.7	8.2	7.8	38	100	112	58	105	75
O.M. Plots only (6)	6.3	(7.3)	(7.3)	1.79	2.08	2.16	.13	.14	.14	7.8	8.7	8.5	51	171	202	64	149	94
Artificials alone (4)	6.2	6.1	5.7	1.71	1.71	1.49	.13	.12	.12	7.5	8.2	7.1	P alone 41	43	49	K alone 48	90	67
Lime+Artificials alone (4)	6.0	8.1	7.3	1.77	1.55	1.50	.13	.11	.12	7.8	7.9	7.2	P alone 28	109	104	K alone 68	86	96
O.M.+Lime+Artificials (4)	6.3	7.9	7.5	1.82	2.18	2.18	.13	.14	.15	8.0	8.9	8.3	P alone (50)	194	302	K alone 65	165	124

(1) Soil sampled, Jan. 1931, before manures were applied

(2) Soil sampled, Jan. 1937, 6 years after manures were applied

(3) Soil sampled, May 1943, 12 years after manures were applied

plots, but the limed soil is still alkaline, and still contains a small reserve (0.05 per cent.) of calcium carbonate. It is diminishing least rapidly in the organic manure plots whose soil has shown a distinct buffering effect.

Artificial manure treatments containing sulphate of ammonia (*i.e.* NP, NK and NPK) have greatly increased the acidity.

(*b*) *Organic Matter Content*:—The Control Plot has lost about 16 per cent. of its original organic matter in 12 years, in spite of the continual addition of root residues. Manuring with artificials has also been accompanied by a marked loss of organic matter (12 per cent.). The limed plot has similarly lost about 28 per cent. of its original organic matter, and liming together with manuring with artificials has been accompanied by a loss of 15 per cent. of organic matter. Thus all treatments not involving organic manure have failed to reduce organic wastage, which, in this soil, over a period of 12 years, may be placed at nearly 20 per cent. This result lends no support to the theory that the organic status of a soil may be raised considerably by the continued application of artificial manures which, by greatly increasing the magnitude of the crop, are believed to bring about a corresponding increase in the amount of root residues left behind to humify in the soil.

Organic manuring has increased the organic matter content of the original soil by about 40 per cent. in 12 years, during which period about 270 tons per acre of organic manure have been applied, or about 13 tons per manured plot. Assuming that the manure loses 50 per cent. of its weight during drying, then if no further loss occurred during its humification in the soil, this amount of material would have increased the organic matter content of the soil (surface 6-inch layer) to about 15 per cent., whereas, in fact, it has raised it only to about 2.5 per cent. Evidently the conditions obtaining in the plots are conducive to rapid wastage of organic matter in the soil.

In the presence of lime, organic manure has given an increase of only 5 per cent, and, in the presence of lime and artificial manures, it has given an increase of about 20 per cent. This result supports the well-known theory that "liming burns away soil organic matter", presumably by creating more suitable conditions for soil micro-organisms that bring about oxidation and nitrification.

(*c*) *Total Nitrogen Content*:—The quantitative effects of the treatments have been the same for nitrogen as for organic matter which contains it.

(*d*) *Carbon Nitrogen Ratio*:—This has narrowed considerably in the Control Plot and in the Limed Plot, presumably through "biochemical deterioration" of their humus component, which is believed to involve rapid nitrification.

Artificial manures alone and with lime have failed to arrest this natural lowering of the ratio.

Organic manuring alone has widened the ratio considerably, but, in the presence of either lime or lime and artificials, it has not appreciably affected it.

(*e*) *Available Phosphate Content*:—This has diminished in the Control Plot, presumably through usage and loss by leaching, by about 20 per cent. in 12 years, but it has increased by about 15 per cent. in the Limed Plot. Liming evidently has released phosphate reserves.

The addition of superphosphate manure has more than maintained the phosphate status, and, in the presence of lime, it has been accompanied by a very large increase in available phosphate content.

Organic manure alone has apparently not affected the available phosphate content, but, in the presence of lime, it has more than doubled it, and in the presence of lime and artificials it has increased it about six-fold. Evidently the magnitude of the dressing of superphosphate is higher than that which is necessary to supply the needs of most field crops and to maintain the phosphate status of the soil, provided the reaction is kept neutral or slightly alkaline, so that phosphate fixation by agencies such as active hydrous iron oxide cannot occur. This agrees with the yield data.

(*f*) *Available Potash Content*:—This has diminished by about 20 per cent. in the Control Plot after 12 years, though a gain was indicated during the first 6-year period. Liming seems to have caused a further decrease in available (exchangeable) potash which might be explained as a result of base exchange.

The addition of sulphate of potash manure alone has raised the available potash status by nearly 40 per cent., and has thus more than sustained the needs of the crops, although the present level of available potash would still not be regarded as adequate for most crops. The further addition of lime has produced no additional rise in potash status.

Organic manure alone has not affected the final available potash status after 12 years, though it caused considerable increase during the first 6-year period. In the presence of lime, it likewise caused no final increase, though the interim increase was apparently large. The addition of sulphate of potash manure together with organic manure and lime has raised the available potash status from 65 to 124 p.p.m., *i.e.* it has nearly doubled it, and has raised the present potash status to a level which would seem to be about adequate for the needs of most field crops.

(2) General Effects of Manurial Treatments

Considering the area as a whole (16 plots), the nutrient status of the soil at the time of the third soil-sampling in May, 1943, was very similar to what it was at the beginning of the experiment in 1931, though its lime, phosphate and potash status may be a little higher at present than what it was originally. The area has produced a considerable bulk of vegetation, however, during its twelve

APPENDIX

Permanent Manurial Experiment—Crops 19-28 Inclusive. Plot Yields (lb. per acre) for Period 1938-43

Crop No. and and Date of Harvest	Plot No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Crop	NK OL	NPK OL	O	—	NP	NK	PK	NPK	NP OL	PK OL	OL	L	NP L	NK L	PK L	NPK L
19 March 1938...	Maize (Cobs) (G) ...	3360	4060	3680	1840	2160	3200	2060	2580	4180	3660	2920	1700	1800	2400	1600	2640
	(Straw) (S) ...	7540	8660	6960	2980	3020	5140	3560	4220	7580	5000	4620	2700	3540	5060	4140	5300
20 August 1938	Sorghum (Whole plants green weight) ...	40760	46540	40840	16980	20060	29700	18700	28560	46140	32900	31780	18900	28120	30860	24000	34700
21 Dec. 1938 ...	Maize (Cobs) (G) ...	1780	1920	2100	760	440	1920	1080	1240	1860	2020	2160	680	540	1660	1240	1760
	(Straw) (S) ...	5140	5600	4260	1780	1280	3460	3260	3860	3920	4700	4000	1680	1540	3880	3220	3480
22 June 1938 ...	Canavalia (Pods) (G) ...	3780	5660	4800	1680	1040	2300	2200	2560	3820	3980	2600	1500	1380	1780	2340	2520
	(Haulm) (S) ...	4000	3840	2440	1200	740	1020	1020	1180	1560	3180	1800	1400	1500	800	1000	1040
23 Sept. 1939 ...	Woolly Pyrol (Whole plants)	5860	7340	6620	2220	100	3960	6740	2820	3100	5560	5100	860	960	6120	3900	4500
24 March 1940...	Sweet Potato (Tubers) (T)	5860	7300	6400	980	780	3580	3540	2520	4500	7300	5600	980	680	1720	1880	2100
	(Vines) (V)	14020	21960	15220	3300	4260	8800	5860	5940	13080	14100	8580	2980	2180	4060	3480	5880
25 May 1941 ...	Sugar Cane (Plant) ...	88500	116800	101320	47280	39120	66200	58500	65500	86220	102800	94200	48800	53700	66620	63000	68640
26 Jan. 1942 ...	Yams (Tubers)	1260	2560	2280	300	820	5260	1360	3080	1340	1260	4420	300	560	560	800	1280
27 Nov. 1942	Maize (Cobs, (G, ...	3560	4560	3120	1880	2240	3200	1760	2440	3920	3240	3560	1320	2480	2240	1680	2200
	(Straw) (S) ...	10600	13800	9080	4920	5200	8640	6560	8920	11600	10120	9720	4160	6680	9720	7400	9320
28 *May 1943 ...	Bengal Beans (Pods) (G)	360	600	600	40	120	80	400	520	120	560	560	20	20	80	480	360
	(Vines) (S)	2200	1600	1800	1000	1920	600	1440	1280	1400	640	2360	3920	4800	3840	3600	4480

* Half-Plot Yields X 2

years of continuous cropping. The "rate of nutrient turnover" has been rapid, although crop growth has comprised a sort of "hand to mouth" existence. There is little sign of a permanent fertility upbuilding, judging by the laboratory data for available phosphate and available potash. Appreciable fixation of nitrogen has gone on in the organic manured plots, however, and perhaps some fixation of phosphate and potash in relatively unavailable form may have taken place in the soil of certain plots, though this has not been tested by bulk chemical analysis.

(*a*) *Organic Manuring* has appreciably raised the organic matter and nitrogen status of the soil of the plots that have regularly received it, and has counteracted a natural tendency toward a narrowing of the carbon-nitrogen ratio and has actually widened the ratio considerably. It has also decreased ten-fold the acidity of the soil.

Organic manuring has considerably improved the phosphate status where accompanied by lime, but not when applied alone. In the absence of artificial manures, it has failed in the long run to raise the potash status to that believed to be adequate for the growth of field crops, or even to maintain it at its original level. In the presence of lime, organic manure has apparently brought about a marked decrease in potash status, but this may be mainly a result of the liming.

(*b*) *Liming* alone at first produced a highly alkaline reaction which has diminished considerably, however, (from pH 8.1 to pH 7.4) during the last six years, corresponding with a continual loss of lime reserves, now only 0.05 per cent. of the weight of the soil (surface 6-inch layer). Liming has greatly enhanced the natural loss of organic matter and has narrowed the carbon-nitrogen ratio. It has appreciably affected the phosphate and potash status of the soil, but the effects seem to have diminished in the last six years, presumably because of the rapid loss of lime by leaching.

These effects of lime have been similar even in the presence of added manures, both organic and inorganic or artificial.

(*c*) *Manuring with Artificials* alone has greatly increased the acidity (nearly 5-fold), and has apparently lowered the organic matter and nitrogen status, with a slight narrowing of the carbon-nitrogen ratio.

It has scarcely affected the ability of the soil to release phosphate and potash.

(i) *Sulphate of Ammonia* (applied together with superphosphate and sulphate of potash) has exerted chief effect on soil reaction, and apparently some effect in reducing the organic matter content, though the evidence for this is inconclusive. Its continued application has not been accompanied by a permanent increase in total nitrogen content, though it may have been instrumental in narrowing the carbon-nitrogen ratio of the residual soil organic matter.

(ii) *Superphosphate* (applied together with sulphate of either ammonia or potash) has slightly raised the available phosphate status of the soil of the plots to which it has been added, especially in the presence of lime, and the dressings have proved sufficient to maintain this status at a value well above the level of adequacy.

(iii) *Sulphate of Potash* (applied together with sulphate of ammonia or with superphosphate) has only slightly raised the available potash status, though a little more in the presence of lime than in its absence.

REVIEW

ROOT DISEASE FUNGI.

By S. D. Garrett.

Price $4.50, *published by the Chronica Botanica Co. Waltham, Mass.,* (*Wm. Dawson & Sons Ltd., London V.*1.)

As the author states in his preface, this is not a textbook, although a wide field of original work is covered, and a useful list of references given. It is short and readable and can be read from cover to cover in a few hours; my main criticism, indeed of an otherwise useful book being that certain sections are too sketchily treated. Not only students of pathology, but agricultural officers, farmers, planters and estate managers will find much here to interest them, and the way in which the diseases are treated from a pathological aspect, will appeal to practical men. An especially welcome feature is the attention which the author has devoted to tropical plantation crops, the diseases of rubber caused by *Fomes* species, and Panama disease of bananas receiving adequate treatment.

In the first half of the book the ecological aspect of the fungi which cause root disease is stressed. They form a part of the soil flora, and on whether their presence is permanent or transient, and, on how they can be influenced by modifying cultural methods, depends the second part of the book, which deals with control measures. Here field crops and plantation crops are treated separately, and in the last chapter a short resume is given of the control of the root diseases of glasshouse crops.

R. E. D. BAKER,
Reader in Mycology.

The Editor requests that any subscriber who fails to receive *Tropical Agriculture* regularly should communicate with him immediately in order that the matter may be rectified.

THE BOTANICAL WORK OF THE CINCHONA MISSION IN SOUTH AMERICA*

When the Japanese invaded the Dutch East Indies in the late winter of 1942, our primary source of quinine was suddenly and unexpectedly cut off. Since our stock piles of this essential drug were inadequate for the urgent needs of a long war, the critical problem was placed in the hands of the Board of Economic Warfare (now the Office of Foreign Economic Administration). Negotiations were gotten under way almost at once with the several Andean republics which a century earlier had produced the world's quinine supply. Although the cinchona agreements consisted essentially of our guarantee to buy all bark above a certain minimum alkaloid content, to furnish technical aid to the bark harvesters and dealers and to establish a plantation programme, in exchange for sole buying privileges, such negotiations are traditionally slow, and it was October, 1942, before the first field party was able to leave Washington.

Dr. F. R. Fosberg and myself, the first two botanists of the cinchona programme, arranged to stop off in Guatemala in order to study briefly the cinchona plantations there before starting our search for wild species in Colombia. Our first surveys were in the Santander provinces of northern Colombia, in the Eastern Andes near Pamplona, since small lots of bark from this region were already appearing on the market. In the months which followed we laboriously studied the forests of the three ranges of the Colombian Andes and came to know in a general way the basic distribution of cinchona species there. *Cinchona pubescens*, an inferior species, was found to occur throughout all three ranges, although it is relatively richer in alkaloids in the eastern range. *Cinchona officinalis*, which usually produces bark of high quality, occurs in Colombia only in the eastern range. This range was found to possess still another source of quinine, quite unsuspected when our work was originally planned. In December, 1942, it had been my good luck to run into large stands of a race of *Remijia pedunculata* on the west slopes of the Eastern Andes north of Bucaramanga. We were astonished to find that the bark of this non-cinchona gave up to 3 per cent. of quinine sulfate with very little admixture of other alkaloids. This same species extends along the eastern foothills of the Colombian Andes from Florencia to Villavicencio, near the type locality where its alkaloid production is very low. The low percentage of quinine may be due to the very sterile, sandy soil, since the high-quality variety grows on deep rich clay in Santander. Another piece of good fortune not foreseen in our original plans was the rediscovery of *Cinchona pitayensis* in the Central Andes, in Cauca province, both by Dr. Fosberg and myself. This little known species had been supposed to be a botanical rarity with very limited geographical distribution. Nevertheless, it turned out not only to be relatively abundant in southern Colombia, but also to be the species richest in alkaloids, with an average of 3 per cent. of quinine sulfate and 5 to 6 per cent. of total crystallizable alkaloids.

In July, 1943, I went to Ecuador to inaugurate exploratory work in the northern provinces, where no cinchona species had ever been collected. My first expedition had as its aim the discovery of *C. pitayensis*, unreported in Ecuador, and in August, 1943, the first-known Ecuadorian stands of this high-quality species were found on the west slope of the Western Andes in the province of Carchi. It occurs in a zone between altitudes of 8,500 and 10,000 feet, and had been over-looked previously because of the tradition in Ecuador that the best races of cinchona occur between 3,000 and 5,000 feet. Explorations were continued and during the next twelve months the belt of *C. pitayensis* was followed southward through the provinces of Carchi, Imbabura, Pichincha and León, more than a hundred miles and well into the southern hemisphere. *Cinchona officinalis*, on the other hand, which had been known previously only in Loja and Azuay provinces of southernmost Ecuador, was followed northward to the Colombian frontier. *Cinchona pubescens* was found to occur throughout the Ecuadorian Andes, and although its bark is generally low in alkaloids, especially quinine, it occasionally produces local races which are surprisingly rich. Several other species were found in the course of survey work, but are of more botanical interest than economic importance. The importance of botanical surveys was demonstrated early in our programme, as can be seen from the foregoing, but it was only during the winter of 1943-1944, a full year later, that the Colombian and Ecuadorian cinchona missions began to receive reinforcements in the form of a number of competent botanists. The survey work in the trackless and precipitous Andean forests of Ecuador just outlined would never have been possible without the help of W. H. Camp, W. B. Drew, G. W. Prescott and Ira L. Wiggins.

Although the best wild cinchona ever known, from which came the cultivated "Ledger" varieties, was discovered in Bolivia, the delicate diplomatic situation prevented the establishment of an official cinchona mission there. However, the best Bolivian barks, like those of the classic Loja region of southern Ecuador and northern Peru, had been exterminated through a destructive exploitation lasting two centuries. The highest quality bark still remaining in Bolivia and much of Peru is so inaccessible that its exploitation in any quantity is almost impossible. Consequently, the great volume of cinchona bark resulting from our work during more than two years has originated primarily in Colombia and Ecuador, even though it is of somewhat inferior quality.

* Reprinted from *Science*, Vol. 101, No. 2616, 1945, pp. 177-178.

The single factor of greatest importance in our work, to which I should attribute much of its success, has been our ability to obtain prompt and accurate analyses of our field samples of bark. No praise can be too high for the chemists who pioneered the cinchona mission laboratories now operating in Bogota, Quito, Lima and La Paz. In cinchona "booms" of previous centuries, analyses could be made only after the shipment reached Europe, months after the bark had been bought and the proceeds spent. This situation led not only to fantastic speculation on good bark but to excessive traffic in worthless barks, and one still hears reminiscences of fortunes made or lost overnight in the "quina" or "cascarilla" business. Through prompt analyses we were able to stop the harvest of poor barks and to encourage the production of good ones. Many species of Remijia, Ladenbergia and other rubiaceous genera closely resemble cinchona to the untrained eye, and our technical aid, both botanical and chemical, has saved many thousands of dollars which dealers would otherwise have "invested".

The quotas of cinchona bark set up in 1942 (which I am not free to mention) have been greatly exceeded by the supplies already harvested, and the cinchona mission botanists are returning one by one to the United States. As a consequence, we may expect publication of extraordinarily important researches on cinchona and related genera, to augment the very few publications which have already appeared on current work (1) (2) (3). The availability of analyses has brought to light physiological distinctions between species, varieties and forms not heretofore suspected, and has provided an important new approach to the interpretation of a complex and badly misunderstood genus. From Dr. W. H. Camp and Dr. F. R. Fosberg, especially, we may certainly anticipate much enlightenment on the taxonomy of this difficult group of plants.

WILLIAM CAMPBELL STEERE.

(1) W. H. Hodge, *Jour. N.Y. Bot. Gard.*, 45: 32-43, 1944.

(2) F. Rosengarten, "History of the Cinchona Project of Merck and Co., Inc., and Experimental Plantations, Inc. 1934-1943". 45 pp. 82 figs. Rahway, N.J. 1944.

(3) W. C. Steere, *Flora* (*Rivesta Inst. Ecuat. Cienc. Nat.*) 4: 1-9, 1944.

EFFICIENCY OF NITROGEN IN SUGAR-CANE PRODUCTION

According to R. J. Borden, in *Hawaiian Planters' Record*, Vol. 48 (1944), No. 2, pp. 65-72, a study was made of 396 field experiments with nitrogen on sugar-cane in Hawaii, with the object of judging the efficiency of applications of nitrogen fertilizer. The first question to be examined was the relation between the yields of plant crops and ratoons. As a rule the plant crops were fully two months older than the ratoons, and this partly accounts for the fact that they have produced more cane and sugar per acre. Both the plant and the ratoon crops have made their optimum yields on the same average amount of nitrogen per acre (174 lbs.), but since the plant crops gave larger yields, they were more efficient users of their applied nitrogen and required it at the rate of one pound less per month. In figures, the plant crops (21.4 months) used less than 2 lbs. of nitrogen per month per ton of cane grown, whereas, for their optimum yields, the ratoon crops (19.1 months) required 2½ lbs. of nitrogen per ton of cane per month. The time of starting the crop in Hawaii has some influence on the efficiency of applied nitrogen. It appears that crops started in the fall and winter get under way slowly on account of the cooler soil temperatures and never quite catch up. As a result, for equivalent lengths of time, they made cane and sugar at slightly lower rates than crops which were started in spring and summer; thus their applied nitrogen is of lower efficiency. As regards pounds of nitrogen per acre, the statistics indicate that there is no advantage for nitrogen applications greater than 150 to 175 lbs. per acre for a plant crop harvested at about 22 months; more than that means greater expenditure of nitrogen per month, per ton of cane and per ton of sugar. For ratoons, there are indications that the per-acre application of nitrogen might be somewhat higher than 175 lbs. Crops harvested in the summer have given lower yields of cane and sugar which were made at slower rates than with crops harvested at other times. Fall-harvested crops have made more cane but relatively less sugar than winter of spring harvestings on account of poorer quality, possibly due to sucker growth which is prevalent in fall-harvest cane. Spring harvesting, because or better quality, is the most desirable. The general relationships between yields of cane and consumption of nitrogen by the crops (plant and ratoon) may be seen from the accompanying table.

Cane and Sugar Yields

Cane Tons/acre	Age of Crop, mos.	Pounds of Nitrogen			
		per acre	per ton cane	per ton sugar	per month
Under 40	17.1	127	3.9	42.3	7.7
40-49	17.4	133	2.9	28.9	7.9
50-59	18.3	140	2.6	24.2	7.9
60-69	19.7	143	2.2	21.3	7.5
70-79	20.1	155	2.1	19.0	7.8
80-89	20.8	156	1.9	17.2	7.6
90-99	22.5	163	1.7	16.6	7.3
over 99	22.4	158	1.4	13.0	7.1

These results show that yields of increase as the application of nitrogen is increased, but the degree of utilization of the nitrogen decreases per ton of cane (law of diminishing increments of yield.) Through it all the figure for pounds of nitrogen per month remains close to 7.6.—(*Sugar*, 1944, Vol. 39, No. 11, p.41.)

CHEMICAL NOTES

(Compiled by the College Department of Chemistry and Soil Science)

Food Yeast

Whereas animals make their protein from the small amounts of organic vegetable protein in the very large quantities of herbage which they consume the yeast cell is able to make its protein from ammonium salts, which are inorganic and manufactured from the nitrogen in the air. The technical question becomes whether yeast can be made in large quantity from carbohydrate material and inorganic nitrogen (ammonia) at a competitive price with meat. Inorganic nitrogen, a product of high-pressure technique, is to-day very cheap and available in unlimited quantity. It is worth while giving some data about yeast production. They are based on U.S. experience. Bakers' yeast is the chief yeast product; it is made to-day from carefully cultured strains having standardized activity in causing bread dough to rise in an appropriate number of minutes. Some 100,000 tons will be made in 1944. The vitamin content is not high, but it is possible to enchance it by changing the nutrient. Brewers' yeast is essentially a by-product of the fermentation of beer and is not a raw material for another industry—more than 12,000 tons are available as a slurry, of which about one-third is recovered as cattle food and about one-tenth used as food or sold in the pharmacy. The vitamin content is some three times as great as that of bakers' yeast. The acceptance of brewers' yeast as food has led to the production in America of this type, grown especially for the yeast, that is, without hops, so that the product need not be debittered. The dried yeast has a high content of the vitamin B complex and retails for some 3s. a pound, a price which is reasonable on the basis of its protein content, which is about 46 per cent. A little calculation shows that yeast protein costs about 6s. 6d. per pound retail, whereas beef, with 19 per cent. protein, selling at 2s. a pound, involves a protein cost of 11s. a pound. These figures are but an indication, but they are very suggestive of what can be done in the way of making protein quickly. Beef protein takes a year or more to make, yeast protein is a matter of twenty-four hours; beef certainly needs a larger acreage.

A specially suitable race of the yeast (*Torula utilis*) for the purpose has been recently developed in London, and factories are understood to be under construction to make it in Jamaica and Mauritius, where its first use will be for the under-nourished children in those Colonies. In the tropics, protein scarcity is often severe, but waste carbohydrates are plentiful. Certain races of yeast multiply so rapidly that the alcoholic fermentation is practically negligible. The yield of dried yeast in practice is 60 per cent. of the fermentable sugar. It has been estimated in Germany that the waste sulphite liquors of the paper mills could make 100,00 tons of dry yeast a year, equivalent to 50,000 tons of protein. A development which is not very remote is the making of fermentable carbohydrates from wood. By what is known as the Scholler process, wood in presence of dilute sulphuric acid at a pressure of 4 atmospheres, the the temperature being taken up to 190°C., is converted into easily fermentable glucose.—(Extract from an address by Dr. E. A. Armstrong, F.R.S. on "Chemistry in the Service of Man" to the Royal Society of Arts, London, published in *Nature*, Vol. 154, No. 5918, 1944.)

* * *

Grass Covers in their Relation to Soil Structure

Emp. J. Expt. Agric. 12, 1944 (21-32). (Uganda Dept. Agric.)

Observations leading to the adoption of the grass rotation for soil regeneration in Uganda are recorded. Under local conditions lime makes no contribution to crumb formation, whether applied alone or with organic manure. Organic manures in the form of green manure, cotton seed, or farmyard produce no increase in the number of water-stable crumbs, possibly because only a small fraction of the added organic matter attains colloidal dimensions. All grasses regenerate soil structure, but there is considerable variation between them. The formation of crumbs is dependent on the amount of clay in the soil, so that the grass rotation cannot be expected to be beneficial on soils of very low colloid content.

* * *

Contribution to the History of the Carbon/Nitrogen Ratio

"The C/N ratio, like many other things, is a German discovery." H. Kaserer gave a paper before the International Congress of Agriculture, Section IIIA, held at Vienna in 1907, on future biological substitutes for Chilean nitrate. In this it was postulated that for every soil a definite equilibrium exists between nitrogen and carbon (humus content). This was followed up in Austria by published dissertations by Felsinger (1911), Felber (1915) and May (1914), discussing various aspects of the C/N relationships in solutions and soils. No other work is mentioned.—(*Soils and Fertilizers*, VII, 4, 1944.)

* * *

Uganda Compost Factory

A compost factory was set up to produce initially 5,000 tons a year from Kampala township wastes. The output is reserved for application to African farms within a radius of five miles and is intended to provide a suitable manure for regenerating soil in overcrowded areas adjoining the town.

The Editor is prepared to consider signed articles for publication in *Tropical Agriculture*. Such articles should normally vary between 1,000 to 6,000 words and may be illustrated if desired.